

## NOTICE OF ENTITLEMENT

We **DELTEC NEW ZEALAND LIMITED**,

of 84 Main Road, Tawa, Wellington 6230, New Zealand,

being the Applicant in respect of Application No. 80057/94,

entitled: **A VARIABLE DIFFERENTIAL PHASE SHIFTER**

state the following:

We are the nominated person to whom we request the patent be granted.

The Nominated Person is entitled to the grant of a patent by virtue of the following facts:

The inventors made the invention in the course of employment by the nominated Person and the Nominated Person would, on the grant of a patent for the invention, be entitled to be assignee of the patent.

The basic application listed in the declaration made under Article 8 of the PCT is the first application made in a Convention country in respect of the invention.

and

The Nominated Person is the Applicant of the application listed in the declaration under Article 8 of the PCT (Claiming Priority).

Address for service in Australia: **CARTER SMITH & BEADLE**, 2 Railway Parade, Camberwell, Victoria, 3124, Australia. (Attorney Code CD)

Dated : 11 June 1996

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**CARTER SMITH & BEADLE**  
Patent Attorneys for the Applicant



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- (71) Applicant(s)  
DELTEC NEW ZEALAND LIMITED
- (72) Inventor(s)  
ROGER JOHN BUTLAND; WILLIAM EMIL HEINZ
- (74) Attorney or Agent  
CARTER SMITH & BEADLE, Qantas House, 2 Railway Parade, CAMBERWELL VIC 3124
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- (57) Claim

1. A variable differential phase shifter comprising:

a coaxial line comprising an inner conductive rod and an outer conductive tube coupled at ends thereof to first and second outputs;

an inner sleeve capacitively coupled to the inner conductive rod and slideable therealong; and

an outer sleeve capacitively coupled to the outer conductive tube and slideable therealong; the inner and outer sleeves being connected to an input and being slideable along said coaxial line in fixed relative relationship to vary the phase relationship of the signals output at the first and second outputs with respect to a signal supplied to the input.



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(71) Applicant (for all designated States except US): DELTEC NEW ZEALAND LIMITED [NZ/NZ]; 84 Main Road, Tawa, Wellington 6230 (NZ).

(72) Inventors; and

(75) Inventors/Applicants (for US only): BUTLAND, Roger, John [NZ/NZ]; 6 Atwood Grove, Churton Park, Wellington 6004 (NZ). HEINZ, William, Emil [NZ/NZ]; 47 Beazley Avenue, Wellington 6004 (NZ).

(74) Agents: TUFFERY, Denis, Eng et al.; Baldwin, Son & Carey, 342 Lambton Quay, Wellington 6001 (NZ).

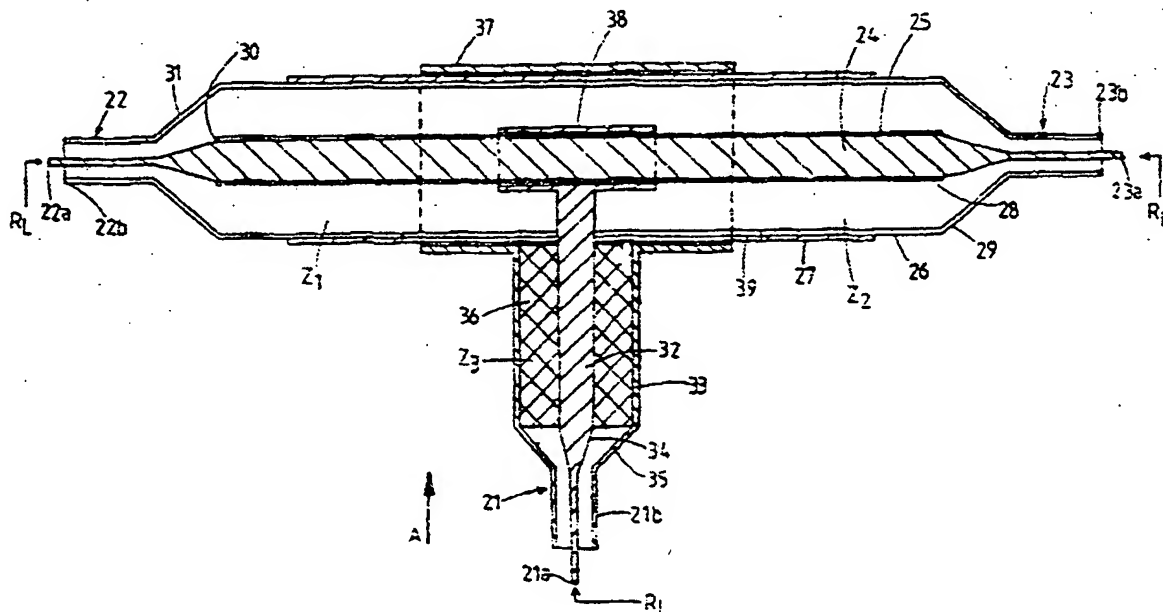
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(54) Title: A VARIABLE DIFFERENTIAL PHASE SHIFTER



(57) Abstract

A variable differential phase shifter is provided. The device provides a continuous variation in phase between two outputs derived from a single output. The device is suitable for application at signal frequencies around 900 MHz, and is constructed in the form of an inner (38) and outer (37) sleeve capacitively coupled to an inner conductive rod (24) and outer conductive tube (26) respectively, wherein the inner (38), and outer (37) sleeves are connected to an input and can be moved in fixed relative relation thereby varying the phase relationship between the two outputs which are connected to the inner rod (24) and outer tube (26). A dielectric layer (25 and 27) may be provided around the inner rod (24) and outer tube (26). An unequal power division version of the device is provided for by the inclusion

## A Variable Differential Phase Shifter

### The technical field

The present invention relates to a variable differential phase shifter. The variable differential phase shifter of the invention allows the phase of two output signals to be continuously varied over a given range with respect to an input signal. The variable differential phase shifter of the invention is particularly suitable for use in tilting the beam of an antenna array.

### Background of the invention

Referring to figure 1 a prior art antenna array consisting of four elements 1-4 is shown. Feed-line 5 supplies a signal to drive the antenna elements 1-4. The signal from line 5 is equally divided between branches 6 and 7. Feed line 6 supplies the driving signal to antenna elements 1 and 2. The signal from branch 6 is further divided between branches 9 and 10. A phase shifter 11 is provided in branch 10 to shift the phase of the signal supplied to antenna element 2 by  $\beta$  with respect to the phase of the signal driving antenna element 1. In branch 7 phase shifter 8 introduces a phase shift of  $2\beta$  with respect to the phase of the signal in branch 6. This phase shifted signal is divided between branches 12 and 13. Antenna element 3 thus receives a driving signal which is phase shifted by  $2\beta$ . A further phase shift element 14 is provided in branch 13 so that the signal driving antenna element 4 is phase shifted by  $3\beta$ .

Accordingly, the antenna elements 1, 2, 3, 4 are phase shifted by an amount  $0$ ,  $1\beta$ ,  $2\beta$ ,  $3\beta$  respectively. In this way the beam of the antenna array can be tilted by a desired amount. Sometimes, to control side lobe levels and beam shape, other than progressive phase shift may be employed. Non-equal power division may also be employed.

In prior art systems phase shifters 8, 11 and 14 may be lengths of cable or active phase shifters. Commonly, active phase shifters using PIN diodes are employed which can be switched on or off to introduce phase shifts in a branch of the feed network. The phase shifters may include a number of PIN diodes to allow a number of delays of different magnitudes in be introduced into a feed path as required.

Such prior art phase shifters suffer from the disadvantage that they can usually only provide phase shifts between respective branches in a stepped manner and cannot usually provide continuous differential phase shifting between branches. Further, high power PIN diodes used in active systems are both expensive, particularly where a large number of antenna elements are employed and have higher losses than the present device. Active systems using PIN diodes also introduce non-linearities and intermodulation.

Other particular advantages of the present invention are as follows:

Because there are no sliding metal contacts, the phase shifter will require little maintenance. If a suitable dielectric is used (for example polytetrafluoroethylene) the sliding friction will be low. This is an advantage when designing mechanical

drive mechanisms or selecting suitable electric  
motors. Because there are no sliding electrically  
conductive surfaces in contact, the phase shift  
5 variation speed can be maximised.

Also, for a required differential phase shift, the  
amount of mechanical movement is half that required by  
in-line phase shifters. This may result in a more  
compact structure. Finally, incorporating the  
10 matching section  $Z_3$  in the phase shifter structure  
reduces the manufacturing cost of a typical feed  
network (such as that shown in figure 1).

#### Disclosure of the invention

It is an object of the present invention to provide a  
15 variable differential phase shifter which overcomes  
the above disadvantages or at least provides the  
public with a useful choice.

According to one aspect of the invention there is  
provided a variable differential phase shifter  
20 comprising:

a coaxial line comprising an inner conductive rod  
and an outer conductive tube coupled at ends thereof  
to first and second outputs;

an inner sleeve capacitively coupled to the inner  
25 conductive rod and slideable therealong; and

an outer sleeve capacitively coupled to the outer  
conductive tube and slideable therealong; the inner  
and outer sleeves being connected to an input and  
being slideable along said coaxial line in fixed  
30 relative relationship to vary the phase relationship  
of the signals output at the first and second outputs

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with respect to a signal supplied to the input.

Preferably a dielectric layer is provided on the exterior of the inner conductive rod and the outer  
5 conductive tube between the inner and outer sleeves respectively. The outputs are preferably transition cones which enable the phase shifter to be coupled directly to coaxial cables.

The input preferably comprises a rod perpendicular to  
10 the inner sleeve which slides within a slot in the outer conductive tube, the rod being coaxial with a tube perpendicular to the outer sleeve and held in fixed relation thereto by an intermediate dielectric, the ends of the rod and tube away from the sleeves  
15 being connected to a transition cone.

There is also provided an unequal power variable phase shifter having a dielectric tube provided around a length of the inner conductive rod adapted so that the power output at the first and second outputs is  
20 unequal.

#### Brief description of the drawings

The invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 2: shows a sectional view of a variable  
25 differential phase shifter according to one aspect of the invention.

Figure 3: shows a view of the outer conductive tube shown in figure 2 viewed in the direction of arrow A.

30 Figure 4: shows an antenna array incorporating the phase shifters of the invention.

Referring to figure 2 an equal power dividing variable differential phase shifter according to one aspect of the invention is shown. All elements shown are circular in cross-section. In alternate embodiments  
5 other cross-sections may be used, such as square, rectangular or hexagonal cross sections.

A coaxial cable 21 supplies a signal to the phase shifter and the outputs of the phase shifter are output via coaxial cables 22 and 23. Central  
10 conductor 21a of coaxial cable 21 is electrically connected to feed rod 32 via conical section 34. Feed rod 32 is electrically connected to inner sleeve 38 which may slide along inner conductive rod 24. Inner conductive rod 24 is preferably provided with a thin  
15 dielectric coating 25 along its length so that inner conductive rod 24 and inner sleeve 38 are capacitively coupled. The ends of inner conductive rod 24 are coupled to inner conductors 22a and 23a via conical sections 28 and 30.

20 The outer conductor 21b of coaxial cable 21 is electrically connected to feed tube 33 via conical portion 35. Feed tube 33 is electrically connected to outer sleeve 37 which can slide along outer conductive tube 26. Outer conductive tube 26 is provided with a  
25 thin dielectric layer 27 along its length upon which outer sleeve 37 slides. The ends of outer conductor 26 are coupled to the outer conductors 22b and 23b via conical sections 31 and 29 respectively.

The dielectric coatings 25 and 27 should be a radio frequency low loss material, and should preferably  
30 have a low coefficient of friction. A suitable material is polytetrafluorethylene.



Feed rod 32 is held in fixed relationship with feed tube 33 by dielectric block 36. Referring to figure 3 it will be seen that outer conductive tube 26 is provided with a slot 39 along its axis. Feed rod 32 can slide within slot 39 as the tee assembly (33, 37, 32, 38) slides to and fro along outer conductive tube 26. It will be appreciated that all components indicated, apart from dielectric materials 25, 27 and 36, will be formed of suitable conductive material, such as brass, copper etc.

The arrangement of inner conductive sleeve 38, dielectric layer 25 and inner conductive rod 24 forms a capacitive coupling. Likewise, the arrangement of outer sleeve 37, dielectric layer 27 and outer conductive tube 26 forms another capacitive coupling. At frequencies around 900MHz or above the reactances of the capacitive coupling are so low that they constitute a direct coupling between sleeves 37 and 38 and outer conductive tube 26 and inner conductive rod 24 respectively.

A signal supplied to input cable 21 will divide between the two outputs (i.e. coaxial output cable 22 and 23) evenly. By sliding the tee section with respect to outer conductive tube 26 the phase of a signal supplied to output coaxial cable 22 and output coaxial cable 23 may be varied. For example, if the tee connection is shifted so that it is to the left of the centre of outer conductive tube 26 then the distance the signal must travel to reach output coaxial cable 22 is less than the distance the signal must travel to reach output coaxial cable 23, hence there is a phase delay of the signal output to coaxial cable 23 with respect to the phase of the signal output to coaxial cable 22. By sliding the tee

section right or left along outer conductive tube 26 the desired phase difference between the outputs 22, 23 may be achieved. It will be appreciated that the phase shifter described allows continuous phase variation between the outputs 22, 23 within the allowed range.

For the equal power dividing variable differential phase shifter shown in figure 2,  $Z_1$ ,  $Z_2$ , and  $Z_3$  are the characteristic impedances of the sections shown and  $R_L$  is the system impedance (in this case 50 ohms).

For equal power division:

$$Z_1 = Z_2 = R_L$$

$$Z_3 = R_L / 2$$

When properly terminated the tapping point impedance  $Z_T$  is equivalent to two  $R_L$  loads in parallel ( $Z_T = R_L / 2$ ).

Thus, a matching section is required between line 21 and the tapping point. It is formed by feed rod 32, feed tube 33 and dielectric material 36. Feed rod 32 is preferably a quarter wavelength long and inner conductive sleeve 38 is preferably between one sixteenth to an eighth of a wavelength long.

If, for example, the system impedance is 50 ohms then

$$Z_1 = Z_2 = 50 \text{ ohms}$$

$$Z_T = 25 \text{ ohms} \quad \text{and}$$

$$Z_3 = 35.4 \text{ ohms}$$

For an unequal power dividing variable differential phase shifter,  $Z_1$  does not equal  $Z_2$ . One option is to let either  $Z_1$  or  $Z_2 = R_L$  so that the other characteristic impedance is less than  $R_L$ , e.g:

$$Z_1 = R_L$$

$$Z_2 < Z_1 \text{ and}$$

$$l_2 = \quad /4$$

10

$$\text{then } Z_3 = \sqrt{\frac{R_L Z_2}{Z_2^2 + R_L^2}}$$

for matching transmission line  $Z_1$  input impedance to  $R_L$  (where  $l_2$  is the electrical length of section  $Z_2$ ).

Transformer  $Z_3$  could be constructed from two sections, one of  $Z_3'$  and the other  $Z_3''$ . Alternatively, it could be made with a tapered characteristic impedance. It will be recognized by a person skilled in the art that these alternatives will increase the operating bandwidth of the device.

Referring now to figure 6, to adjust the impedance of section  $Z_2$  to the desired value a dielectric tube 40 may be secured to inner sleeve 38 which is slideable relative to inner conductive rod 24. It will however be appreciated that other means may be used to alter the impedance of section  $Z_2$ .

It should also be appreciated that in other embodiments the phase shifter may be driven via coaxial cable 22 or 23. If the phase shifter is driven by coaxial cable 22 then the output at coaxial cable 23 stays in constant phase relationship with the input at coaxial cable 22. Only the output at coaxial cable 21 varies as the t-section slides to and fro. It will be appreciated that for such a configuration the characteristic impedances would have to be adjusted, using similar equations to those described above but with  $Z_1$  and  $Z_3$  interchanged. Dielectric tube 36 may be replaced by spacers at the ends thereof if less dielectric material is required.

Referring now to figure 4 an antenna array incorporating the phase shifter of the invention is shown. The antenna array consists of antenna elements 40 to 43. Phase shifters 45 to 47 are of the form shown in figure 2. A signal supplied from feed line 44 is divided by phase shifter 45 between branches 48 and 49. Phase shifter 46 divides the signal from feedline 48 between antenna elements 40 and 41. Phase shifter 47 divides the signal supplied on feedline 49 between antenna elements 42 and 43.

If the tee of phase shifters 46 and 47 is moved up a distance  $d$  from their central positions and the tee of phase shifter 45 is moved up a distance to  $2d$  from its central position then phase shifts of  $0, \beta, 2\beta, 3\beta$  will result for the antenna elements 40, 41, 42 and 43. It will thus be appreciated that the beam of the antenna may be tilted by any desired amount by shifting the phase shifters 46 and 47 a distance  $d$  from centre and phase shifter 45 a distance  $2d$ .

In one embodiment a mechanical coupling may be provided so that the tees of phase shifters 46 and 47 are shifted in unison and the tee of phase shifter 45 is moved twice the distance of phase shifters 46 and 47. The tees of phase shifters 46 and 47 may be linked by a rigid member to ensure that they move in unison whilst the tee of phase shifter 45 may be linked to the member via a pivoted arm so that the tee of phase shifter 45 moves twice the distance of the tees of phase shifters 46 and 47.

A possible mechanism is shown in figure 5. Points 51 and 52 of member 50 may be linked to the tees of phase shifters 46 and 47 to ensure that they move in unison. Member 53 may be pivotally connected to member 50 at point 54. One end 55 of member 53 may be connected to a pivot point mounted to an antenna housing. The other end 56 may be connected to the tee of phase shifter 45. The length 58 between pivot point 54 and point 56 may be the same as the length 57 between pivot point 54 and pivot point 55. In this way the tee of phase shifter 45 moves twice the distance moved by the tees of phase shifters 46 and 47.

It will be appreciated that there are many other possible mechanisms that may be used to adjust the tees in the required manner. Length 57 may be greater than or less than length 58 if other than progressive phase shifting is required. Non-linear linkages may be employed where other than progressive phase shifting is required. The linkages may be manually adjusted or driven by suitably geared motors, stepper motors or the like.

The present invention thus provides a relatively inexpensive continuously variable differential phase

shifter suitable for use in high power phase shifting applications. The phase shifter of the present invention may find particular application in high power antenna arrays.

5 Where in the foregoing description reference has been made to integers or components having known equivalents then such equivalents are herein incorporated as if individually set forth.

10 Although this invention has been described by way of example it is to be appreciated that improvements and/or modifications may be made without departing from the scope or spirit of the invention.

### Industrial Applicability

5 The variable differential phase shifter of the present invention may find application in the construction and operation of antenna arrays wherein beam tilting or squinting is required. Such arrays are commonly found in telecommunications applications such as cellular networks. The variable differential phase shifter may also be substituted for PIN diodes in situations where a device is required for varying the phase of two output signals.

Claims

1. A variable differential phase shifter comprising:
  - a coaxial line comprising an inner conductive rod and an outer conductive tube coupled at ends thereof to first and second outputs;
  - 5 an inner sleeve capacitively coupled to the inner conductive rod and slideable therealong; and
  - an outer sleeve capacitively coupled to the outer conductive tube and slideable therealong; the inner and outer sleeves being connected to an input and being slideable along said coaxial line in fixed relative relationship to vary the phase relationship of the signals output at the first and second outputs with respect to a signal supplied to the input.
- 15 2. A variable differential phase shifter as claimed in claim 1 wherein a dielectric layer is provided on the exterior of the inner conductive rod and the outer conductive tube between the inner and outer sleeves respectively.
- 20 3. A variable differential phase shifter as claimed in any preceding claim wherein the outputs are adapted to be coupled directly to coaxial cables.
4. A variable differential phase shifter as claimed in claim 3 wherein the outputs have transition cones to connect to coaxial cables, having different diameters from the outputs, so as to obtain minimum VSWR.
- 25



5. A variable differential phase shifter as claimed in any preceding claim wherein the input comprises a second coaxial line comprising:

5 a second inner conductive rod and a second outer conductive tube, wherein said second inner conductive rod is coaxial with the second outer conductive tube, and said second inner conductive rod and said second outer conductive tube are connected substantially perpendicularly to the inner and outer  
10 sleeves respectively, and wherein the second inner conductive rod slides within a slot in the outer conductive tube.

6. A variable differential phase shifter as claimed in claim 5 wherein the input is adapted to be coupled  
15 directly to coaxial cables.

7. A variable differential phase shifter as claimed in claim 5 or 6 wherein the second coaxial line has a transition cone at the end distant from the sleeves, to connect to coaxial cable having a different  
20 diameter to the input so as to obtain minimum VSWR.

8. A variable differential phase shifter as claimed in any of claims 5 to 7 wherein the second inner conductive rod is held in fixed relation to the second outer conductive tube by an intermediate dielectric.

25 9. A variable differential phase shifter as claimed in any preceding claim wherein a dielectric tube is provided around a length of the inner conductive rod adapted so that the power output at the first and second outputs is unequal.

30 10. A variable differential phase shifter as claimed in claims 5 to 9 wherein the radial dimensions of said

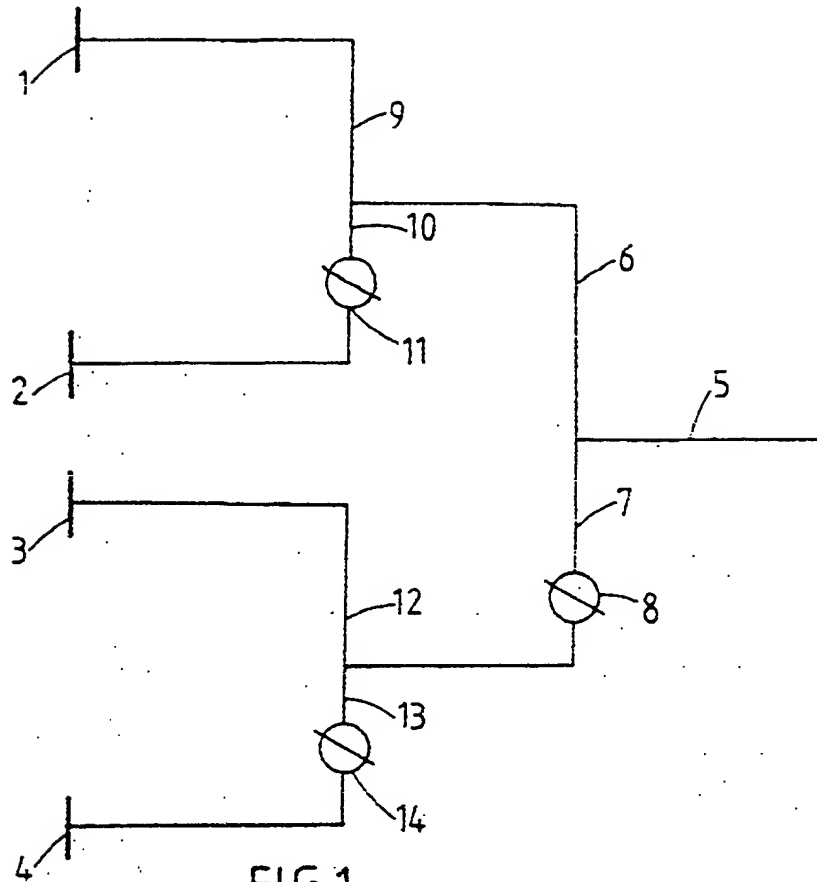
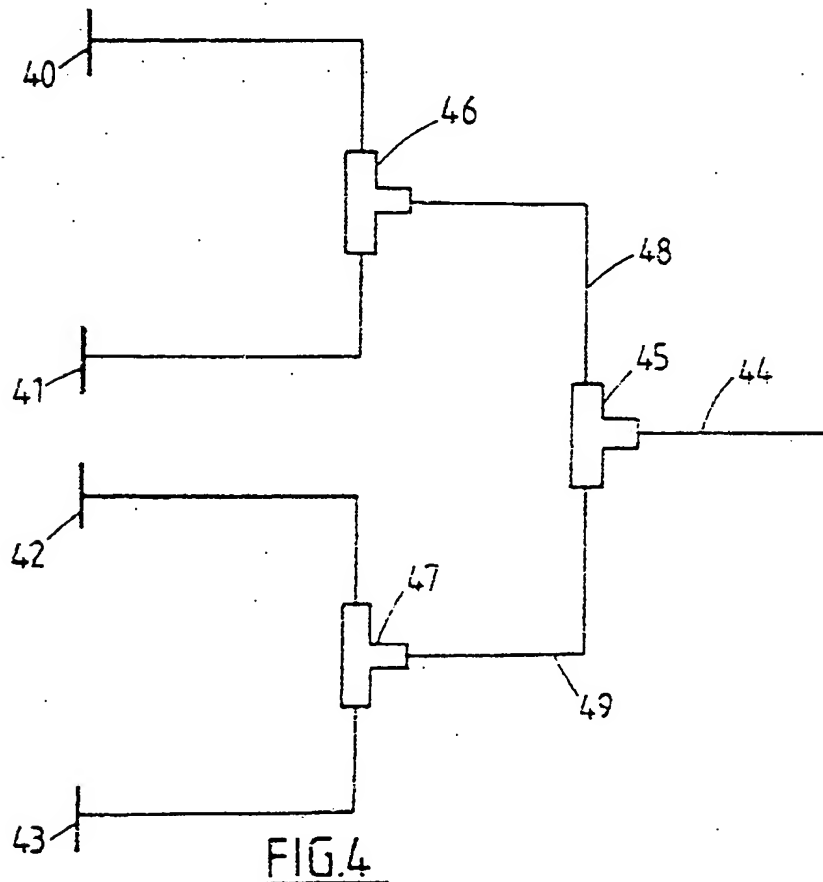
second inner conductive rod and said second outer conductive tube vary singly or in combination along their respective lengths providing a varying characteristic impedance.

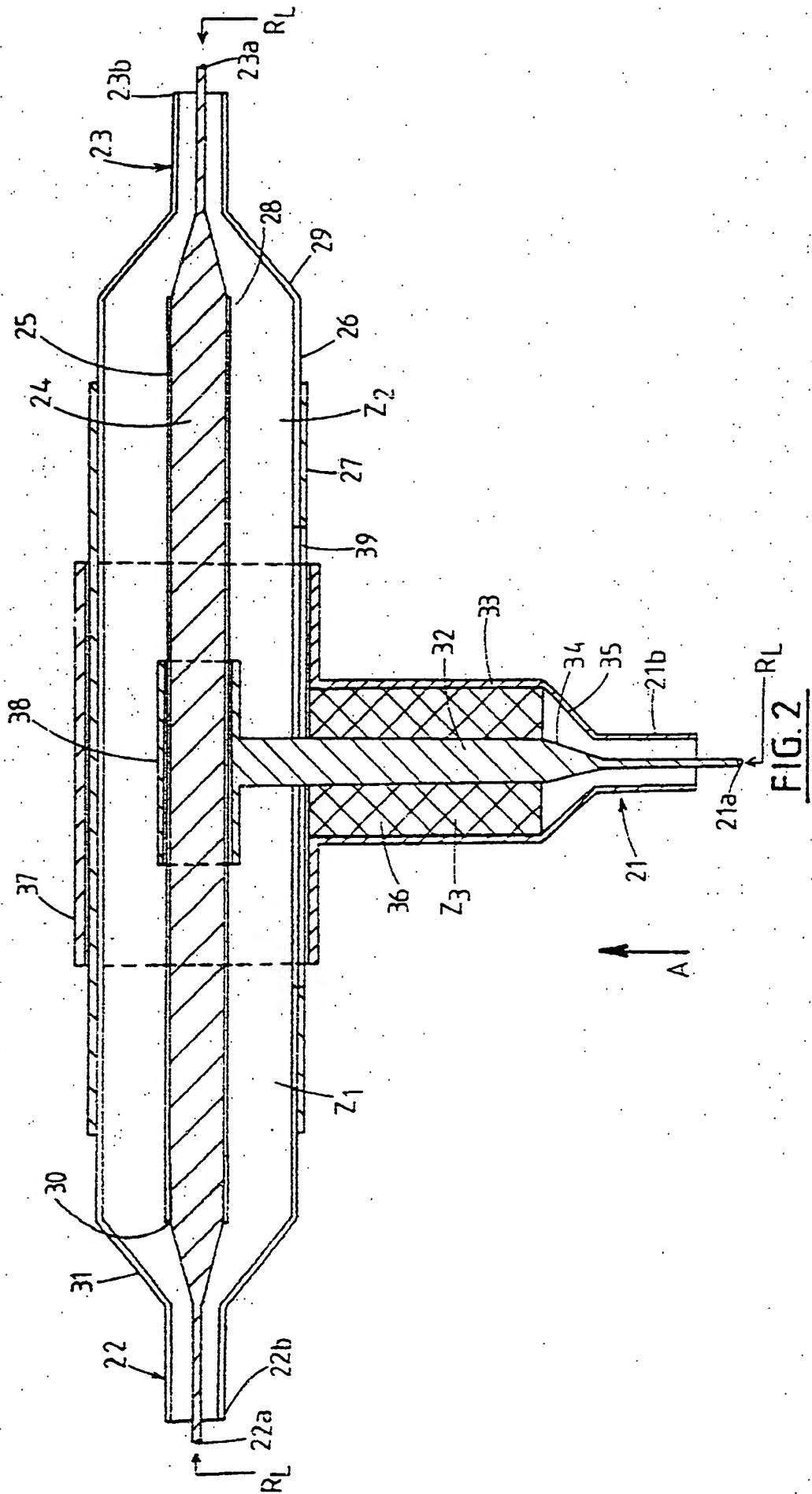
- 5 11. A variable differential phase shifter as claimed in claims 8 to 10 wherein the radial dimensions of said second inner conductive rod, second outer conductive tube and intermediate dielectric vary singly or in combination along their respective lengths providing a varying characteristic impedance.
- 10 12. A variable differential phase shifter as claimed in any of claims 5 to 11 wherein said second coaxial line is adapted to provide a tapering characteristic impedance.
- 15 13. A variable differential phase shifter as claimed in any one of claims 5 to 8 wherein said second coaxial line is adapted to provide two different characteristic impedances.
- 20 14. A variable differential phase shifter substantially as hereinbefore described with reference to Figures 2 to 4 of the accompanying drawings.

DATED: 17 December 1997

CARTER SMITH & BEADLE  
Patent Attorneys for the Applicant:  
DELTEC NEW ZEALAND LIMITED



FIG. 1FIG. 4



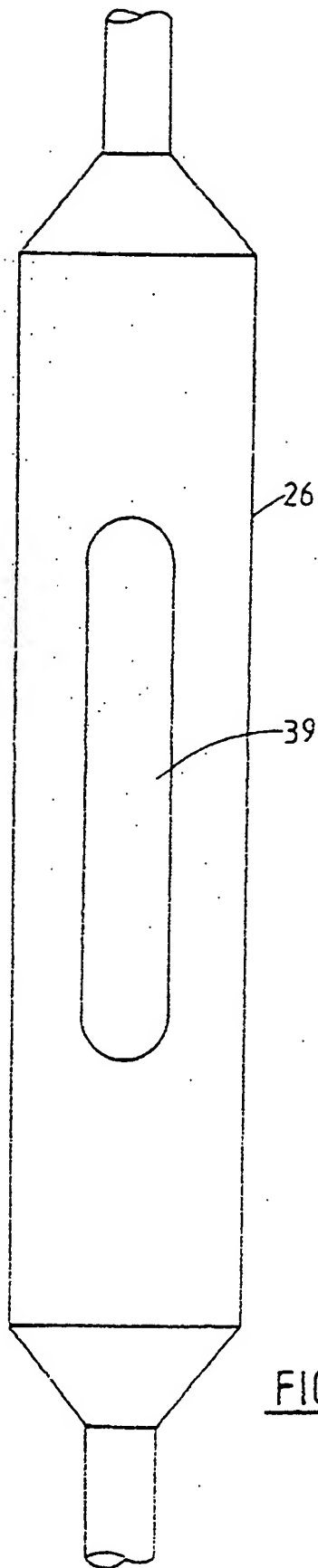
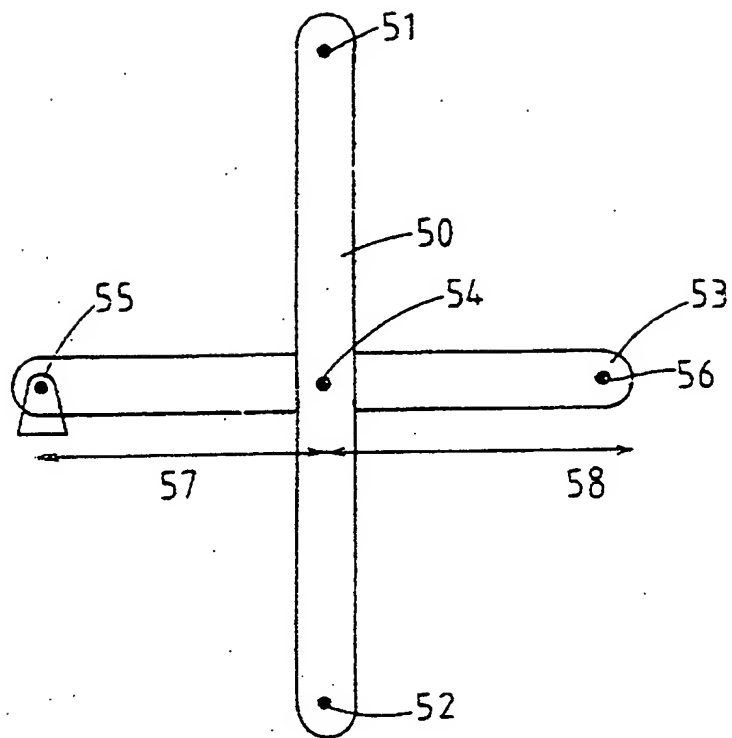
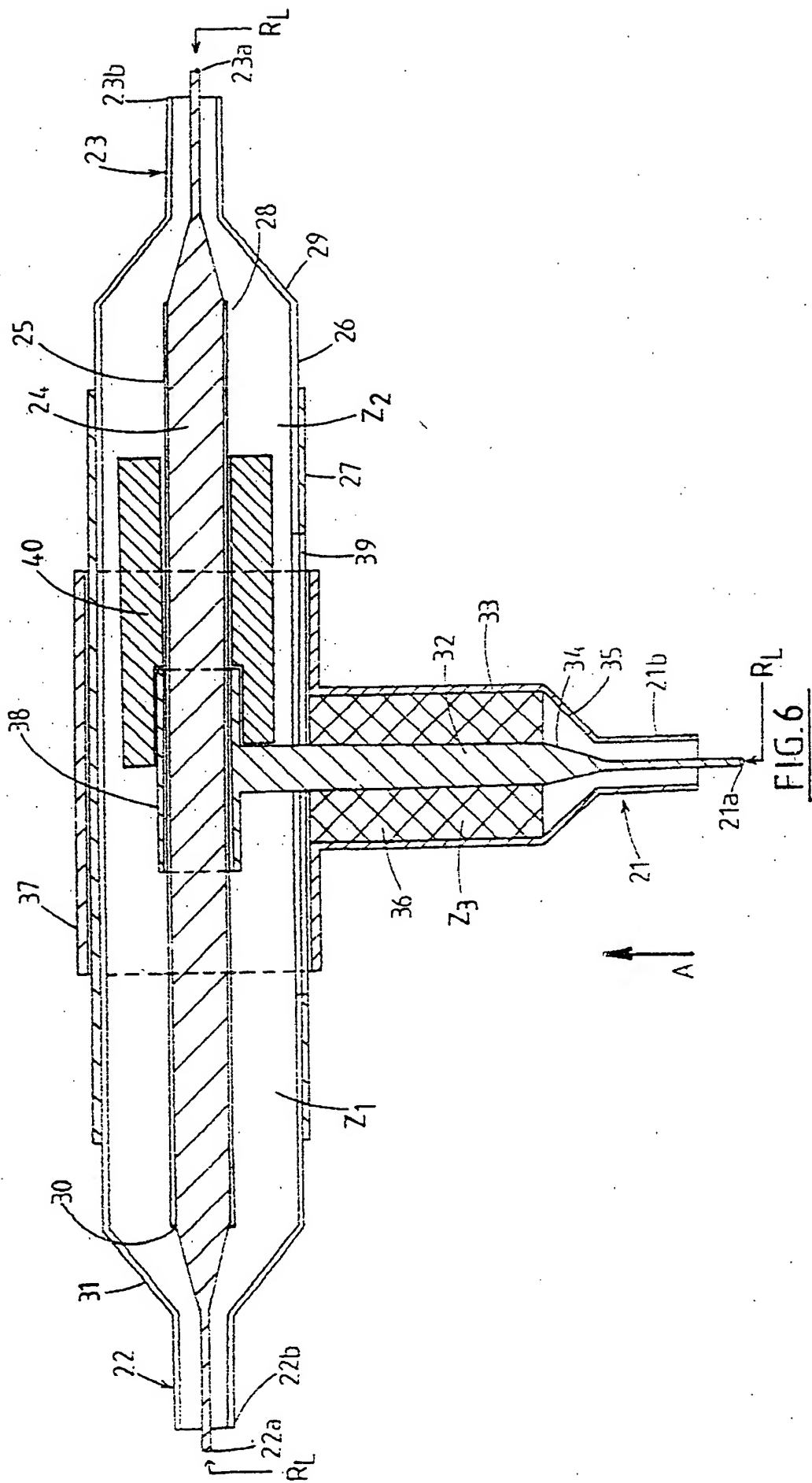
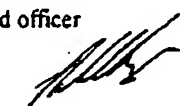


FIG.3

FIG. 5



<b>A. CLASSIFICATION OF SUBJECT MATTER</b> Int. Cl. <sup>6</sup> H01Q 3/32; H01P 1/18, 5/12  According to International Patent Classification (IPC) or to both national classification and IPC				
<b>B. FIELDS SEARCHED</b>  Minimum documentation searched (classification system followed by classification symbols) IPC H01Q 3/32; H01P 1/18, 5/12  Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched AU : IPC as above				
Electronic data base consulted during the international search (name of data base, and where practicable, search terms used) WPAT JOPAL CAPRI				
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.		
A	Derwent Abstract Accession No. 93-125240/15, Class W02, SU.A, 1734142 (RADIO COMPONENTS RES INST) 15 May 1992 (15.05.92) abstract			
A	Derwent Abstract Accession No. 92-204705/25, Class W02, JP.A, 4134902 (TOSHIBA KK) 8 May 1992 (08.05.92) abstract			
A	Derwent Abstract Accession No. 92-144518/18, Class W02, JP.A, 4032302 (JAPAN ATOMIC ENERGY) 4 February 1992 (04.02.92) abstract			
<div style="display: flex; justify-content: space-between;"> <div style="text-align: left;"> <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C.         </div> <div style="text-align: left;"> <input checked="" type="checkbox"/> See patent family annex.         </div> </div>				
<table style="width: 100%; border: none;"> <tr> <td style="width: 50%; vertical-align: top;"> <p>* Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </td> <td style="width: 50%; vertical-align: top;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&amp;" document member of the same patent family</p> </td> </tr> </table>			<p>* Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&amp;" document member of the same patent family</p>
<p>* Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&amp;" document member of the same patent family</p>			
Date of the actual completion of the international search 17 January 1995 (17.01.95)		Date of mailing of the international search report <b>3 Feb 1995 (3.2.95)</b>		
Name and mailing address of the ISA/AU  AUSTRALIAN INDUSTRIAL PROPERTY ORGANISATION PO BOX 200 WODEN ACT 2606 AUSTRALIA  Facsimile No. 06 2853929		Authorized officer    R. FINZI  Telephone No. (06) 2832213		



C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate of the relevant passages	Relevant to Claim No.
A	EP.A, 357085 (CSELT CENT LAB TELE) 7 March 1990 (07.03.90) abstract	
A	Patent Abstracts of Japan, E-267, page 3, JP.A, 59-90401 (NIPPON DENKI K.K.) 24 May 1984 (24.05.84) abstract	

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member			
EP	357085	AU	40031/89	CA	1318370
		IT	1223796	JP	2113601
				IT	8867787
				US	4982171
END OF ANNEX					

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